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Charge of the massive leptons

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A simple picture of the massive leptons emerges by invoking a $\pi\lambda\!\!\!^{-2}$ cross section for vacuum virtual photons to stimulate an isolated lepton to emit an additional virtual photon. This reaction mechanism leads to the storage of a lepton's energy and momentum in the surrounding cloud of virtual photons. The stimulated-emission process allows for the exchange of virtual photons between a pair of leptons, and thus an estimate the fine-structure constant. A simple sharp low-energy cutoff for the exchanged photons, associated with near-field effects, results in a calculated charge of 1.65×10^{-19} C. The discrepancy with experiment might be reduced by including additional computational complexity.

Quantum electrodynamics (QED) [1-4] is one of the most successful and tested theories ever developed, and can be viewed as a pinnacle of human thought. However, the nature of the fundamental unit of charged is not understood and QED calculations require its input via an experimental determination of the fine-structure constant. In the present study we find that a simple reaction mechanism predicts a fundamental unit of charge of $\sim1.6\times10^{-19}$ C.

We assume that vacuum virtual photons interact with isolated charged leptons with a cross section of $\pi\lambda\!\!\!^{-2}$ for photon energies less than a high-energy cutoff $\varepsilon_H=2\pi mc^2$. The assumed consequence of this interaction is the stimulated emission of an additional virtual photon, while the incident vacuum virtual photon proceeds on in its original state. This process is depicted in Fig. 1. The assumed "sharp" cutoff at ε_H is likely unphysical, however, we here test this simplistic approach and keep it if its consequences appear satisfactory.

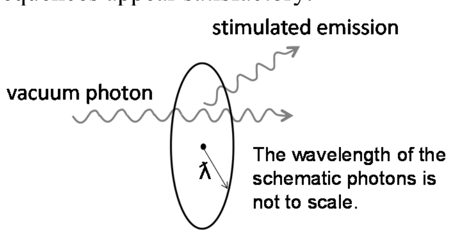

Fig. 1. Depiction of a stimulated virtual emission generated by the passage of a vacuum virtual photon within a reduced wavelength of a point-like lepton.

The stimulated emission rate from an isolated charged lepton can be determined by multiplying the production cross section by the number density of vacuum virtual photons [5] by the speed of light

$$R=\int_0^{\varepsilon_H}\pi\lambda\!\!\!^{-2}\frac{\varepsilon^2 d\varepsilon}{\pi^2\hbar^3c^3}c=\int_0^{\varepsilon_H}\frac{d\varepsilon}{\pi\hbar}=\frac{\varepsilon_H}{\pi\hbar}. \qquad (1)$$

The stimulated-emission from a fixed-mass object, like a charged lepton, violates conservation of energy and momentum, and would not be allowed if only classical physics was assumed. However, we invoke the time-energy uncertainty principle to allow the stimulated emission to travel away from the lepton at the speed of light and "disappear" on a time scale of $\hbar/(2\varepsilon)$. This gives an exponential distribution of survival times, $P(t)\propto\exp(-2t\varepsilon/\hbar)$.

Combining the above assumptions gives an average virtual-photon energy, above the virtual-photon vacuum ground-state energy, associated with the presence of an isolated charged lepton of

$$\bar{E}=\int_{\varepsilon=0}^{\varepsilon_H}\int_{t=0}^{\infty}\frac{\varepsilon}{\pi\hbar}\frac{t\exp(-2\varepsilon t/\hbar)\,dt}{\int_0^\infty\exp(-2\varepsilon t/\hbar)\,dt}d\varepsilon=mc^2. \quad (2)$$

The particle's energy being contained in the surrounding cloud of stimulated virtual photons gives the correct total energy as a function of velocity, because of the different rates of the passage of time between different inertial frames that control the time-energy uncertainty principle. The Doppler shift of the stimulated virtual photons associated with a particles velocity gives the result that its momentum is stored in the surrounding cloud. The mean time spacing between simulated emissions is $\hbar/(2mc^2)$. The corresponding constant jiggling (recoiling) of the leptons gives them an effective size of approximately the particle's reduced Compton wavelength $\lambda\!\!\!^{-}_C$, is reminiscent of the Zitterbewegung from the Dirac equation [5], and is likely related to the high-energy cutoff, ε_H, introduced above.

For the exchange of photons between a pair of leptons, both the emission and reabsorption of the stimulated virtual photons would be completely suppressed by energy conservation if only classical physics was assumed. We temporarily ignore this important fact and use the emission rate given by Eq. (1) and a $\pi\lambda\!\!\!^{-2}$ reabsorption cross section, to calculate the average repulsive force associated with the exchange of virtual photons between a lepton pair with a separation distance $d \gg \lambda\!\!\!^{-}_C$

$$\bar{F}=2\int_0^\infty\frac{d\varepsilon}{\pi\hbar}\frac{\varepsilon}{c}\frac{\pi\lambda\!\!\!^{-2}}{4\pi d^2}=\frac{\hbar c}{2\pi d^2}\int_0^\infty\frac{d\varepsilon}{\varepsilon}. \qquad (2)$$

The factor of two is because of the two-way exchange of the photons between the lepton pair. This force was obtained by assuming the exchange of a stimulated virtual photon generates a momentum change of ε/c in both the emitting and absorbing particles in a direction away from their corresponding partner particle.

The reabsorption by the partner lepton reestablishes conservation of energy but only after an exchange time of $t_{ex}=d/c$. As discussed above, the probability that a stimulated virtual photon is still in "existence" after a time t is given by $\exp(-t/\tau)$ with $\tau=\hbar/(2\varepsilon)$. This leads to a photon-exchange flux-reduction factor of $\exp(-\varepsilon/T_{ex})$ with an effective exchange temperature of $T_{ex}=\hbar c/(2d)$.

To remove the infinite force generated by the $1/\varepsilon$ term in Eq. (2) we need to consider how the photon-particle interaction cross section is altered when an incoming photon does not start from a source particle an infinite distance from the absorbing particle. An estimate of these near-field corrections can be obtained via simple semi-classical arguments. For example, based on the assumed interaction cross section of $\pi ƛ^2$, each massive lepton can be thought of as a sphere of radius $ƛ$ when emitting and absorbing photons with a reduced wavelength of $ƛ$. Within this simple picture, near-field effects should be small, but growing, as their separation decreases through $\sim 2ƛ$ (as the two semi-classical spheres start to overlap), and be strong for photons exchanged between particles separated by $d < ƛ$, with the virtual photons increasingly losing their ability to interact with the particles, as individual objects, as the separation distance decreases towards zero. This behavior is analogous to the interaction properties of closely spaced classical antennas [6]. Given these simple arguments, it seems reasonable that a rough estimate of the universal charge could be obtained by setting the reabsorption cross section to zero for photon exchanges with $ƛ$ larger than the separation distance between the particle pair, d. Modifying Eq. (2) accordingly, including the $\exp(-\varepsilon/T_{ex})$ factor discussed above, and switching to energy in units of the exchange temperature, $T_{ex}=\hbar c/(2d)$, where the point $ƛ=d$ corresponds to $\varepsilon = 2$, gives the result

$$\bar{F} \sim \frac{\hbar c}{2\pi d^2} \int_2^\infty \frac{\exp(-\varepsilon)d\varepsilon}{\varepsilon}, \qquad (3)$$

with a corresponding fine-structure constant of

$$\alpha \sim \frac{1}{2\pi} \int_2^\infty \frac{\exp(-\varepsilon)d\varepsilon}{\varepsilon} \sim 1/128.5. \qquad (4)$$

The corresponding predicted fundamental unit of charge is $q=1.65\times10^{-19}$ C, and differs from the known value by ~3%. We speculate that this discrepancy is associated with various complexities not included in the present study. For example: the sharp low-energy cutoff at $d=ƛ$ should be replaced by a better estimate with a smooth transition; additional quantum effects may modify the simple exponential in Eq. (3), perhaps into the Planckian factor of $1/[\exp(\varepsilon)-1]$; and the inclusion of higher-order effects involving exchanges represented by Feynman diagrams with more than two vertices. The semi-classical exchange force associated with Eq. (3) can only generated repulsion. An attractive force between oppositely charged leptons can be obtained by assuming the opposite charge is associated with a hole in a Fermi-sea of negative-energy particles [5].

The present study suggests that the energy, momentum, and the electric field of the charged leptons are all associated with a cloud of stimulated virtual photons surrounding a point-like massless particle, and charge is an emergent property generated by a simple interaction between point-like particles and the electromagnetic vacuum. Additional work on photon-particle near-field corrections is needed.

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